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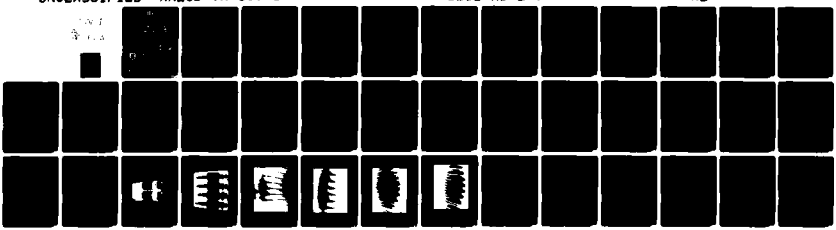

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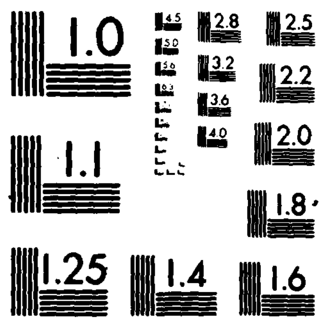

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TECHNICAL REPORT ARLCD-TR-80018

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EFFECT OF CHROME PLATING ON THE WEAR CHARACTERISTICS AND BALLISTIC PERFORMANCE IN THE 155-MM M198 ARTILLERY SYSTEM

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FEBRUARY 1981

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Wear tests were conducted on both a 0.25-mm thick, chrome-plated M199 cannon for the M198 artillery system and the standard M199 steel cannon. During testing, M483A1 projectiles were fired from both tubes with the high zone propelling charge M203. After every 250 rounds, precision range groups including each of the main projectiles in the 155-mm system were fired from each tube. After firing 1,750 rounds, wear in the chrome-plated tube in the region of the origin of rifling was about one-half that of the steel tube. In addition, the chrome-plated tube showed only slight wear for the first 2.5 meters down bore from the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) origin of rifling, a significant improvement over the steel tube. Although an earlier chrome-plated tube firing M549A1 projectiles showed considerable muzzle wear, none resulted from the M483A1 firings. Recovered projectiles fired from the chrome-plated tube after 1,500 and 1,750 rounds showed one-third more rotating band wear than those fired from the steel tube after the same number of rounds. However, the rotating band wear did not affect the range precision or deflection of the rounds nor was it caused by free run as was demonstrated by the torsional acceleration tests. After 1,750 rounds, none of the projectiles fired from the chrome-plated tube experienced any velocity or range reduction, while the M549A1 projectile fired from the steel tube after the same number of rounds lost 21.3 m/s velocity and 500 meters in range. Further testing is planned to define condemnation criteria and wear life for both the steel and the chrome-plated tubes.

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TABLES

FIGURES

INTRODUCTION

In previous testing of 155-mm steel cannon M199, the tube was condemned after 1,750 rounds were fired with the high zone M203 propelling charge because the rotating band was stripping and causing short rounds with the high explosive, rocket-assisted projectile M549A1. Fired with the original high zone M203 propelling charge the steel tube had a wear-life goal of 5,000 rounds with all 155-mm projectiles, but this requirement was reduced to 2,500 rounds when testing indicated that this goal might take considerable technological developments to achieve. When it was determined that the steel tube would not achieve the required 2,500 round wear life (ref 1), a chrome-plated M199 cannon was tested with the M203 propelling charge and the M549A1 projectile. The chrome-plated tube showed an improvement in wear (fig. 1) at the origin of rifling and for the first 2.5 meters down bore, but considerable muzzle wear on the lands in one quadrant of the tube was observed (ref 2). The corresponding body engraving, which was definitely projectile related, occurred full length on the M549A1 projectile bourrelet but, again, on only one quadrant of the projectile. The M549A1 projectile evidenced engraving as deep as 0.66 mm while the M483A1 cargo-carrying projectiles and the M107 high-explosive projectiles showed little or no body engraving. After 1,800 rounds the chrome-plated tube caused no velocity drop or range loss in the M549A1, M483A1, and M107 projectiles. This was a significant improvement over the steel tube, which caused the M549A1 to lose 21.3 m/s in velocity and 500 meters in range after 1,800 rounds. A total of 2,300 rounds were fired from the chrome-plated tube, and although the percentage of range-probable error and deflections increased, condemnation criteria were not established. Since the M483A1 projectile, which is used substantially more often than the M549A1, experienced no body engraving when fired from the chrome-plated tube, it was selected for wear testing to establish condemnation criteria and to determine if the wear-life goal of 2,500 rounds could be reached with the chrome-plated tube.

WEAR TESTING

Test Components

Weapon Systems

1. M199E9 tubes with muzzle brake, Serial Number (SN) 27687 (steel) and SN 88 with 0.23 to 0.25-mm chrome plating.

2. Carriage mount M39, SN 10

3. Spindle with straight through, low flame hole with wrench slot with two 0.0254-meter bumps to provide 0.0254-meter standoff.

4. Recoil system M45, SN 8

Projectiles

1. M549A1 (HE) IOP-77K 030-002, IOP-77K 030-001

2. M549A1 (Inert) IOP 78H 001S081

3. M483A1 (HE) KN 77J 006-001, KN 77J 005-001, KN 77K 006-001, LS 77M 020-015

4. M483A1 (Inert) KN 78G 001-SO 20, KN 78G 001-SO 03

5. M107 LOP G4-196 and LOP G43-135

Propelling Charges

1. M203 IND 79A-069807

2. M4A1 BAJ 63457

Fuzes

1. M557 (PD) MA19-3, MA 38-2, MA 33-17

2. M557 (MT) HAT 78 D003-004 with spotting charge

3. M78 Dummy MOR 78C 001-002

4. M54 AT (MT) BGD-500-1

5. M73 Dummy FLP 77J 002-005, FLP 79C 002-023

Primers

1. LS 130-116

2. LS 159-66

Instrumentation

1. M11 copper crusher gages were used to measure the maximum chamber pressure.

2. G.E. radar was used to record all projectile muzzle velocities.

3. A thermal warning device showed the external tube temperature during all firings.

Chrome Plating Process

A 155-mm M199 tube, SN 88, with the interior diameter machined oversized by several tenths of a millimeter, was used for chrome plating. Additional material was removed from the lands and grooves by electropolishing, and the chrome was electroplated on the tube walls. Approximately 0.2 mm to 0.25 mm of chrome were deposited directly on the lands, while 60% less was deposited on the grooves to achieve a conventional hard chrome plating.

Test Procedure

The two tubes were fired alternately every 250 rounds, beginning each time with a range precision group of 36 rounds: 12 M483A1 and 12 M549A1 projectiles fired with M203 propelling charges and 12 M107 projectiles fired with M4A2 propelling charges. Expenditure rounds consisting of M483A1 projectiles and M203 propelling charges were fired between precision groups. Daily pullover measurements and borescope inspections were performed. Normal stargage inspections were conducted in a new tube and after approximately every 250 rounds. Propelling charges were conditioned for firing at 294 K. Muzzle velocities and chamber pressures were recorded during the first ten rounds fired each day. The rate-of-fire did not exceed one round per minute and firing was discontinued if the tube's external temperature exceeded 394 K as indicated by the thermal warning device on the exterior of the tube. Projectiles fired for recovery were inert loaded with wax and equipped with M78 dummy fuzes. Projectiles were recovered after firing 1,250, 1,500, and 1,750 rounds in the steel tube, and after firing 1,500 and 1,750 rounds in the chrome-plated tube. After a total of 1,871 rounds fired from the steel tube and 1,800 rounds from the chrome-plated tube, torsional acceleration was measured on the M549A1 projectiles in both gun tubes.

TEST RESULTS

Wear Curves

Wear curves for both steel and chrome-plated tubes were compared after about 1,750 rounds (fig. 2). Several wear curves of both tubes in which M483A1 projectiles were fired at various stages of testing are shown in figures 3 and 4.

Ballistic Data

Pressure, muzzle velocity, and range precision data for both the steel and chrome-plated tubes for the M549A1, M483A1, and M107 projectiles are presented in tables 1 through 6.

Recovered Projectiles

Typical projectiles recovered after firing from both the steel and chrome-plated tubes are shown in figures 5 and 6.

Borescope Pictures

Representative borescope pictures of the steel and chrome-plated tubes at the beginning and end of the wear test are shown in figures 7 through 10.

Torsional Acceleration

Data on the torsional acceleration of the M549 projectile in a series of 155-mm M199 steel and chrome-plated cannons can be compared in table 7.

DISCUSSION

Wear

The difference in wear profiles, depending upon whether M549A1 projectiles or M483A1 projectiles are fired, is shown in figure 3. Because of these wear patterns, the condemnation criteria in a steel tube was tentatively established as 2.54-mm at 1.056 meters or 1.524-mm at 1.524 meters from the rear face of the tube. More wear occurs at the origin of rifling in a steel tube firing M483A1 projectiles than one firing M549A1 projectiles. However, the tube firing the M549A1 appears to have more down bore tube wear which is believed to be responsible for stripping of the rotating band causing short rounds and, consequently, condemnation of the tube (figs. 2 and 3).

Wear occurred at the origin of rifling on the two chrome tubes tested, but did not extend the 2.54 meters down bore as in the steel tube. However, the one firing M549A1 projectiles predominately experienced significant muzzle wear, whereas the one firing M483A1 projectiles shows none after 1,800 rounds. The wear in the chrome-plated tubes at the origin of rifling is about 45% less than in the steel tube. No down bore tube wear or muzzle wear has occurred in the chrome-plated tube firing M483A1 projectiles predominately. This family of projectiles is fired about 80% of the time in actual field use and for this reason it is believed that the 2,500-round wear life can be reached.

Ballistic Data

A comparison of the percentage of range-probable error for the steel and the chrome-plated tubes indicates that this data is at least as good for the chrome-plated tube as for the steel. This is also true for the range dispersion. However, the muzzle velocities and pressure behave differently in the two tubes. In the steel tube the muzzle velocity starts at a given value, increases slightly with rounds fired, and falls slowly as the tube wears. This occurs regardless of the projectile fired, although the velocity drop and corresponding range loss are always greater with the M549A1 projectile than with the M483A1, which has a heavier rotating band that obturates better. Again, the standard deviations for the muzzle velocities in the chrome-plated tube are equal to, or better than, those in the steel tube. The muzzle velocities in the chrome-plated tube always start out higher for any given projectile than in the steel tube, and continue to increase with additional rounds fired. The muzzle velocity increase with the M549A1 projectile and the M107 projectile is about 4.6 to 6.1 m/s higher initially than in the steel tube, but it does not increase dramatically up to 1,800 rounds. However, with the M483A1 projectile, the muzzle velocity starts out 5.1 m/s higher than in the corresponding steel tube and increases an additional 9.1 m/s by 1,750 rounds. The peak pressures in both tubes behave similarly to the muzzle velocities. There is a slight pressure increase in the steel tube which gradually decreases as the tube wears. The pressure in the chrome-plated tube always starts out higher than that of the corresponding steel tube with all the projectiles fired. The pressure increase is about 14 MPa with the M549A1 and M107 projectiles over the duration of the test. However, a 27.6 MPa increase occurred from round 1 to 1,750 with the M483A1 projectile. These pressure increases in the chrome-plated tube could cause a safety problem, and methods of reducing the pressure by changing the propellant grain web in the propelling charge are under investigation.

Recovered Projectiles

Three sets of projectiles were recovered after firing 1,250, 1,500, and 1,750 rounds from the steel tube, while two sets were retrieved after 1,500 and 1,750 rounds were fired from the chrome-plated tubes. Projectiles recovered from the chrome-plated tube have approximately one-third more wear than those recovered from the steel tube. A step in the engraved part of the rotating band is observed where this wear occurs (fig. 6). There is no noticeable correlation between rotating band wear and the number of rounds fired in either the steel or chrome-plated tube.

Wear Profiles

The borescope pictures reveal distinctive differences in the wear profiles of the steel and the chrome-plated tubes. The steel tube wears uniformly across the lands with rounds fired (figs. 7 and 8). From the stargage reports, the chrome-plated tube exhibits wear only at the origin of rifling and almost none anywhere else in the tube. However, an examination of the lands about 25 to 40-mm forward of the commencement of rifling reveals an entirely different wear profile. The lands do not wear uniformly in this case, but wear more on the sides than in the middle (figs. 9 and 10). (A stargage only measures the high points on the lands and thus would not be expected to show this wear.) The necking down of the lands in the region 25 to 40-mm in front of the commencement of rifling increases as the rounds fired from the chrome-plated tube increase. The necking down could be caused by the large engraving stresses accompanied by the large heat input which causes the chrome to spall from the sides of the lands, but not the top. The corresponding follow-on heat input wears the lands where chrome is lost. One possible explanation for the increase in pressure in the chrome-plated tube and the excess wear on the projectile rotating bands fired from this tube could be the necking down of the lands. The rotating band of the projectile engraves initially at the origin of rifling, then travels down to the region of necking where the projectile moves further over the necked down land. However, when it passes the necked down region it encounters a full land width which causes a second engraving on the land resulting in increased wear on the rotating band. This condition slows the projectile, increases the shot start pressure, and, thus, allows the peak pressure to increase.

Torsional Acceleration

Torsional acceleration measurements were performed with the M549A1 projectiles in both the steel and the chrome-plated tubes after about 1,800 rounds to insure that the projectiles were being properly spun in both tubes. In the steel tube, there is great wear on the lands while little wear occurs in the grooves, thus possibly inducing free run. The chrome-plated tube had a necked down region where free run could occur. The results in these tubes (table 7) showed that neither tube had any significant torsional impulse, although the previous chrome tube firing M549A1 projectiles predominately, had a severe torsional impulse after 2,500 rounds. The ratio of the torsional acceleration at the beginning of projectile travel to that at the peak torsional acceleration which occurs at peak pressure is given in table 7. The value of 1.96 in chrome-plated tube SN 83 means that the torsional acceleration on the M549A1 projectile is almost twice as great in the beginning of travel than at peak pressure. This large torsional acceleration impulse causes the rotating band to strip resulting in rounds that fall short of the target. The value of 0.67 observed in chrome-plated tube SN 88 is accepted because the torsional acceleration at the beginning of travel is much less than at peak pressure. This torsional acceleration impulse in chrome-plated tube SN 88 occurred at the distance of travel where the lands were necked down. Since the torsional acceleration tests with the present steel tube SN 27687 and chrome-plated tube SN 88 were acceptable, it was decided to continue the firing until wear condemnation criteria was reached for each tube.

CONCLUSIONS

The chrome-plated tube offers significant improvement in wear (45%) over the steel tube at the origin of rifling and down bore for the first 2.5 meters.

After 1,800 rounds, the chrome-plated tube showed no velocity drop or range loss for the M549A1, M483A1, and M107 projectiles. This again is a significant improvement over the steel tube.

The steel tubes wear differently, depending on which projectile (the M549A1 or the M483A1) is fired more often. The M549A1 causes more down bore wear for the first 1.5 meter from the rear face of the tube while the M483A1 causes slightly more wear at the origin of rifling.

The chrome-plated tube firing M483A1 projectiles predominately, did not show any muzzle wear after firing about 1,800 rounds while significant muzzle wear was observed with a previous chrome-plated tube firing M549A1 projectiles predominately.

The differences in wear profiles between the steel and chrome-plated tubes on the lands near the origin of rifling is verified in borescope pictures. In the steel tube the wear across the lands is uniform while in the chrome tube in a region about 25 to 40-mm in front of the commencement of rifling a necking down of the lands occurs which does not show in the stargage readings.

The necking down of the lands in the chrome-plated tube may cause a double engraving of the projectile's rotating band which increases the shot start and corresponding pressure and also increases the rotating band wear.

The torsional acceleration measurements in both tubes showed no unacceptable high peaks after approximately 1,800 rounds.

REFERENCES

1. Firing Report No. 13703, dated 15 March 1977, Yuma Proving Ground, AZ, entitled, "Development Test II of Howitzer, 155mm XM198 (Tube Wear Phase with XM203 Propelling Charge)."

2. J. A. Lannon and A. C. Vallado, "Effect of Chrome Plating on Wear Characteristics and Ballistic Performance on the 155mm Howitzer," JANNAF Propulsion Meeting, Anaheim, CA, March 1979.

Table 1. Range precision data for M549A1 projectile with M203 propelling charge
155-mm M199 steel cannon tube SN 27687

Tube rd no.	Muzzle vel (m/s) Mean	Muzzle vel (m/s) σ*	Pressure (MPa) Mean	Pressure (MPa) σ*	Range precision Mean (m)	Range precision σ*	Range precision RPE (m)	Range precision RPE (%)	Range precision DPE (mils)
25-36	822.7	1.7	304.6	5.2	19838	60.2	40.6	0.20	0.22
245-256	826.3	2.0	310.9	6.0	19299	59.2	39.9	0.21	0.16
490-501	822.0	1.9	308.0	4.9	20042	87.1	58.7	0.29	0.38
740-751	818.1	2.0	299.5	3.2	19668	75.26	50.8	0.26	0.28
990-1001	815.0	3.3	293.4	4.4	19743	93.05	62.8	0.32	0.29
1240-1251	811.7	1.1	293.9	3.6	19235	67.4	45.5	0.24	0.34
1508-1519	807.4	2.1	286.8	3.5	19811	76.2	51.4	0.25	0.45
1859-1870	802.5	1.6	283.3	3.5	19378	123.3	83.2	0.42	0.40

* Standard deviation

Table 2. Range precision data for M483A1 projectiles with M203 propelling charge 155-mm M199 steel cannon tube SN 27687

Tube rd	Muzzle vel (m/s)		Pressure (MPa)		Range precision				
no.	Mean	σ*	Mean	σ*	Mean (m)	σ*	RPE (m)	RPE (%)	DPE (mils)
13-24	794.0	1.5	311.8	6.5	17404	88.2	59.5	0.34	0.56
233-244	796.1	1.7	317.3	6.0	16962	77.39	52.2	0.31	0.26
478-489	798.3	1.5	315.3	4.8	17722	59.06	39.8	0.22	0.31
728-739	792.5	1.5	307.1	3.1	17423	124.48	83.96	0.48	0.38
978-989	792.8	1.3	309.9	7.7	17479	67.03	45.2	0.26	0.31
1228-1239	788.5	2.0	306.1	5.5	16961	46.2	30.5	0.18	0.37
1496-1507	790.3	2.4	306.8	4.1	17579	90.6	31.1	0.35	0.46
1847-1858	788.2	1.7	310.0	3.6	17422	86.9	58.7	0.34	0.47

* Standard deviation

Table 3. Range precision data for M107 projectiles with M4A2 propelling charge
155-mm M199 steel cannon tube SN 27687

Tube rd	Muzzle vel	(m/s)	Pressure	(MPa)	Range precision				
no.	Mean	σ*	Mean	σ*	Mean (m)	σ*	RPE (m)	RPE (%)	DPE (mils)
1-12	567.2	1.0	167.5	3.6	11326	38.0	25.6	0.23	1.15
221-232	571.5	1.3	179.0	5.2	10960	38.4	25.9	0.24	0.18
466-477	570.0	1.1	175.9	2.9	11598	29.4	19.8	0.17	0.29
716-727	566.6	1.3	170.9	2.8	11315	48.3	32.6	0.24	0.45
966-977	565.4	1.3	170.5	2.8	11340	35.9	24.2	0.21	0.43
1216-1227	564.5	0.7	165.4	3.5	11011	26.0	17.6	0.16	0.16
1484-1495	563.9	2.0	162.7	7.7	11381	50.5	20.5	0.18	0.57
1835-1846	564.8	0.9	166.2	2.9	11304	34.4	23.2	0.21	0.54

* Standard deviation

Table 4. Range precision data for M549A1 projectiles with M203 propelling charge 155-mm M199 chrome-plated cannon tube SN88

Tube rd no.	Muzzle vel (m/s)		Pressure (MPa)		Range precision				
	Mean	σ*	Mean	σ*	Mean (m)	σ*	RPE (m)	RPE (%)	DP (mils)
26-37	828.4	1.3	312.7	4.8	19938	101.7	68.6	0.34	0.41
256-267	832.1	1.7	321.2	3.7	20062	114.0	76.9	0.38	0.26
489-500	832.1	1.6	325.8	3.9	19610	73.0	49.3	0.25	1.0
724-735	831.8	1.5	318.1	5.9	19965	95.26	64.3	0.26	0.26
991-1002	830.0	1.6	318.4	3.2	20142	84.96	57.3	0.28	0.31
1242-1253	830.0	1.4	317.2	3.8	20729	91.38	61.6	0.33	0.30
1483-1494	831.5	1.9	324.0	4.4	21126	92.6	62.4	0.30	0.51
1786-1797	831.8	2.0	329.6	4.2	19975	88.2	59.5	0.30	0.38

* Standard deviation

Table 5. Range precision data for M483A1 projectiles with M203 propelling charge 155-mm M199 chrome-plated cannon tube SN88

Tube rd no.	Muzzle vel (m/s) Mean	Muzzle vel (m/s) σ*	Pressure (MPa) Mean	Pressure (MPa) σ*	Range precision Mean (m)	Range precision σ*	Range precision RPE (m)	Range precision RPE (%)	Range precision DP (mils)
14-25	799.2	1.1	320.6	4.7	17476	66.23	44.7	0.26	0.31
244-255	801.9	1.2	323.0	6.0	17577	65.4	44.1	0.25	0.32
477-488	804.7	2.0	328.2	4.4	17262	46.99	31.7	0.18	0.27
741-752	802.8	2.2	327.4	3.9	17497	56.9	38.4	0.22	0.43
979-990	804.1	0.9	333.4	4.7	17746	60.97	41.1	0.23	0.37
1230-1241	805.3	1.6	331.6	4.5	17399	96.42	65.0	0.37	0.42
1471-1482	805.9	1.8	337.3	2.9	17672	44.1	29.8	0.17	0.42
1764-1775	809.2	1.9	348.2	4.2	17659	70.4	47.5	0.26	0.23

* Standard deviation

Table 6. Range precision data for M107 projectiles with M4A2 propelling charge 155-mm M199 chrome-plated cannon tube SN88

Tube rd	Muzzle vel	(m/s)	Pressure	(MPa)	Range precision				
no.	Mean	σ*	Mean	σ*	Mean (m)	σ*	RPE (m)	RPE (%)	DP (mils)
2-13	572.4	1.0	178.3	3.7	11343	34.32	23.1	0.20	0.37
232-243	573.6	1.3	182.1	3.2	11511	48.47	32.7	0.28	0.31
465-476	575.5	1.0	183.0	6.9	11202	36.69	24.8	0.22	0.27
712-723	574.5	1.4	187.9	3.1	11490	31.33	21.1	0.18	0.26
967-978	574.5	1.1	187.2	2.6	11584	26.8	18.1	0.16	0.43
1218-1229	575.5	1.2	184.7	3.5	11380	37.98	25.6	0.23	0.21
1459-1470	573.9	1.4	183.8	4.0	11509	27.65	18.6	0.16	0.47
1752-1763	574.5	2.0	186.8	4.1	11373	43.4	29.3	0.18	0.89

* Standard deviation

Table 7. Torsional acceleration test results of the M549 projectile 155-mm M199 and chrome-plated cannons

Tube no.[1]	Peak impulse time ($\times 10^{-3}$ sec)	Avg A_{TANG}[2] (G's)	Max axial acel (G's)	Avg $\frac{A_{TANG}}{A_T}$[2]	Comments
83	3.0	2625	13.500	1.94	Very large torsional impulses
88	2.4	875	13,000	0.67	Small torsional impulses

1 Tube number 27687 - no significant torsional impulse

2 Ratio of torsional acceleration

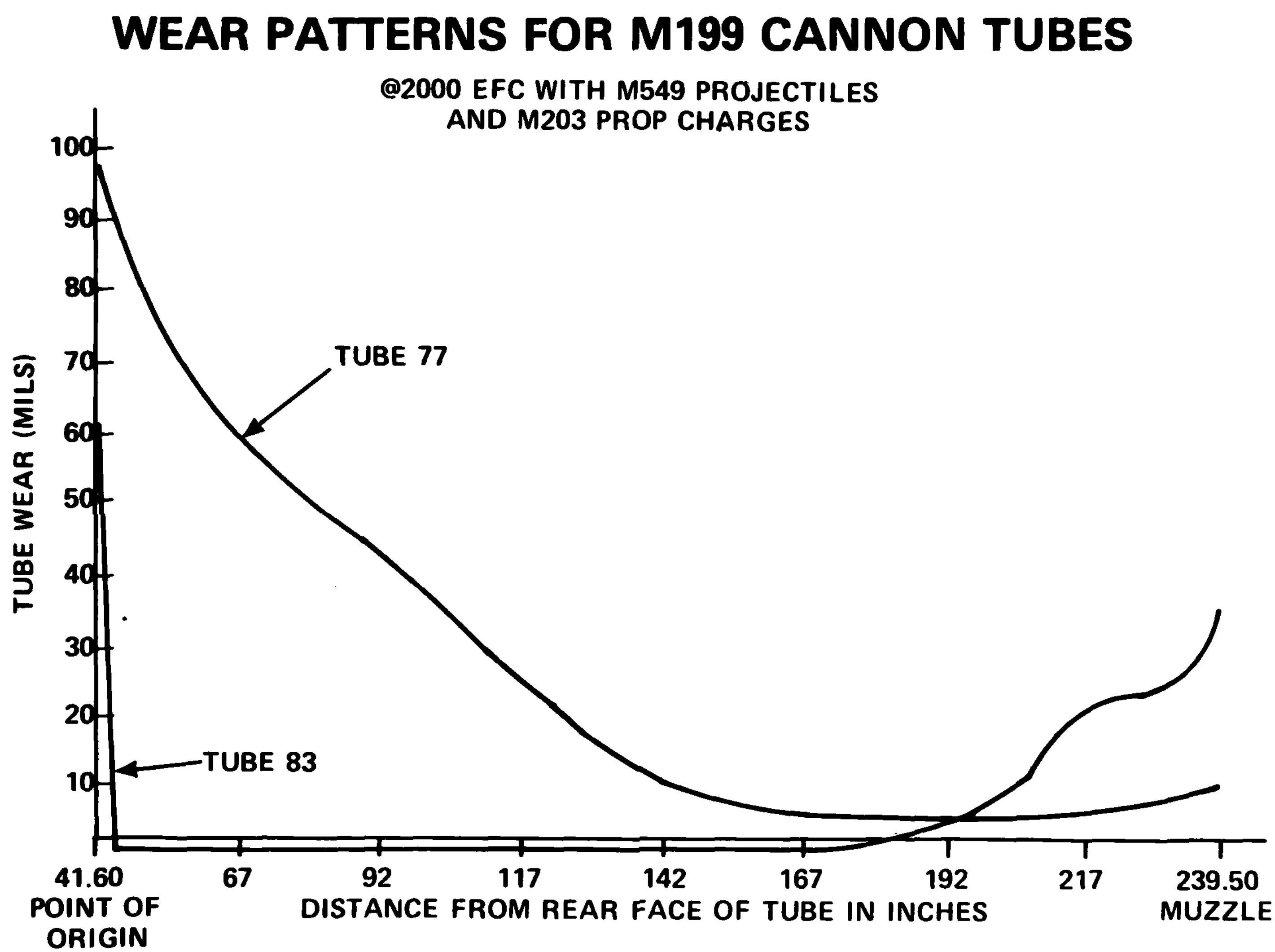

Figure 1. Wear pattern for M199 tube firing M549A1 projectiles

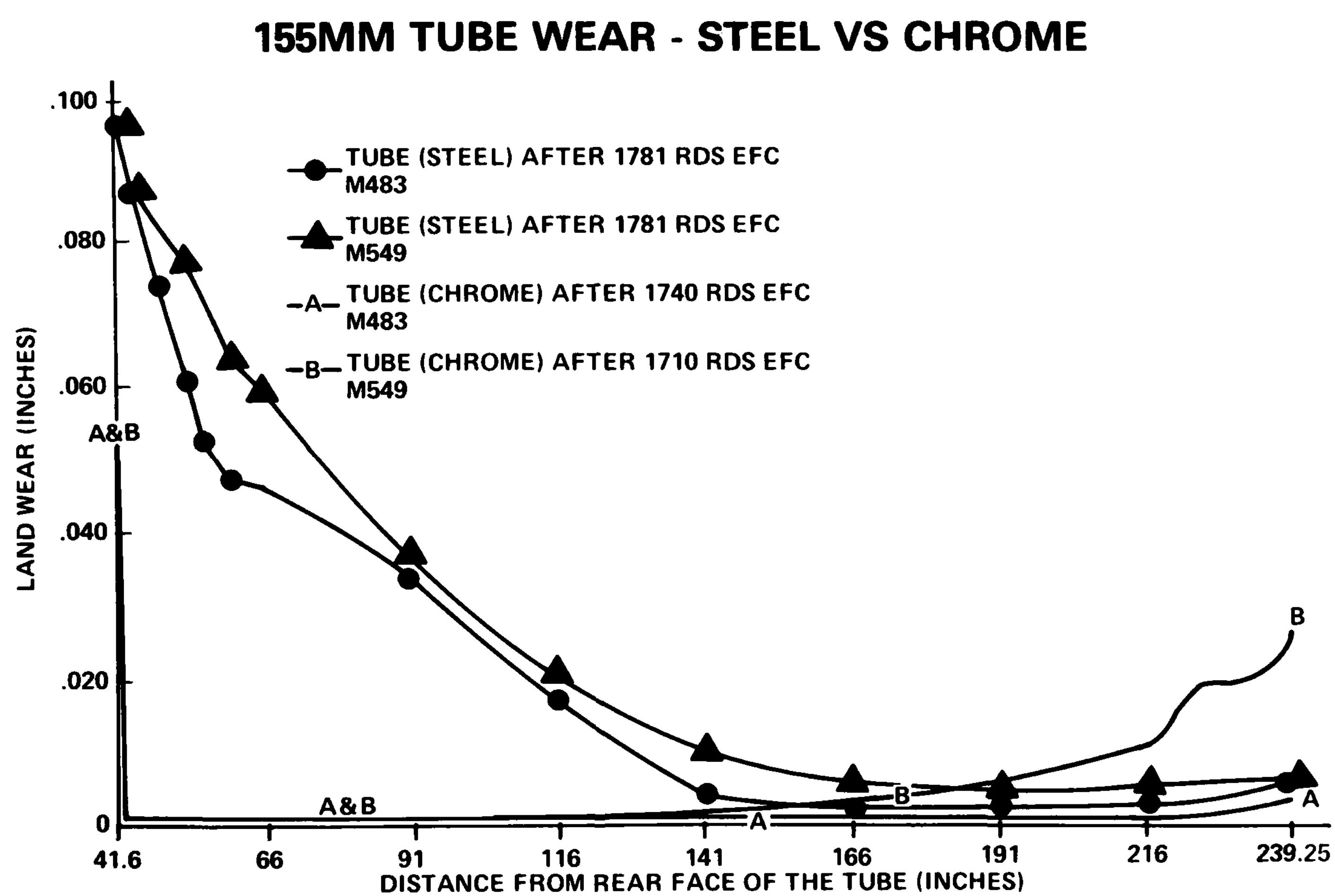

Figure 2. 155-mm tube wear - steel vs chrome

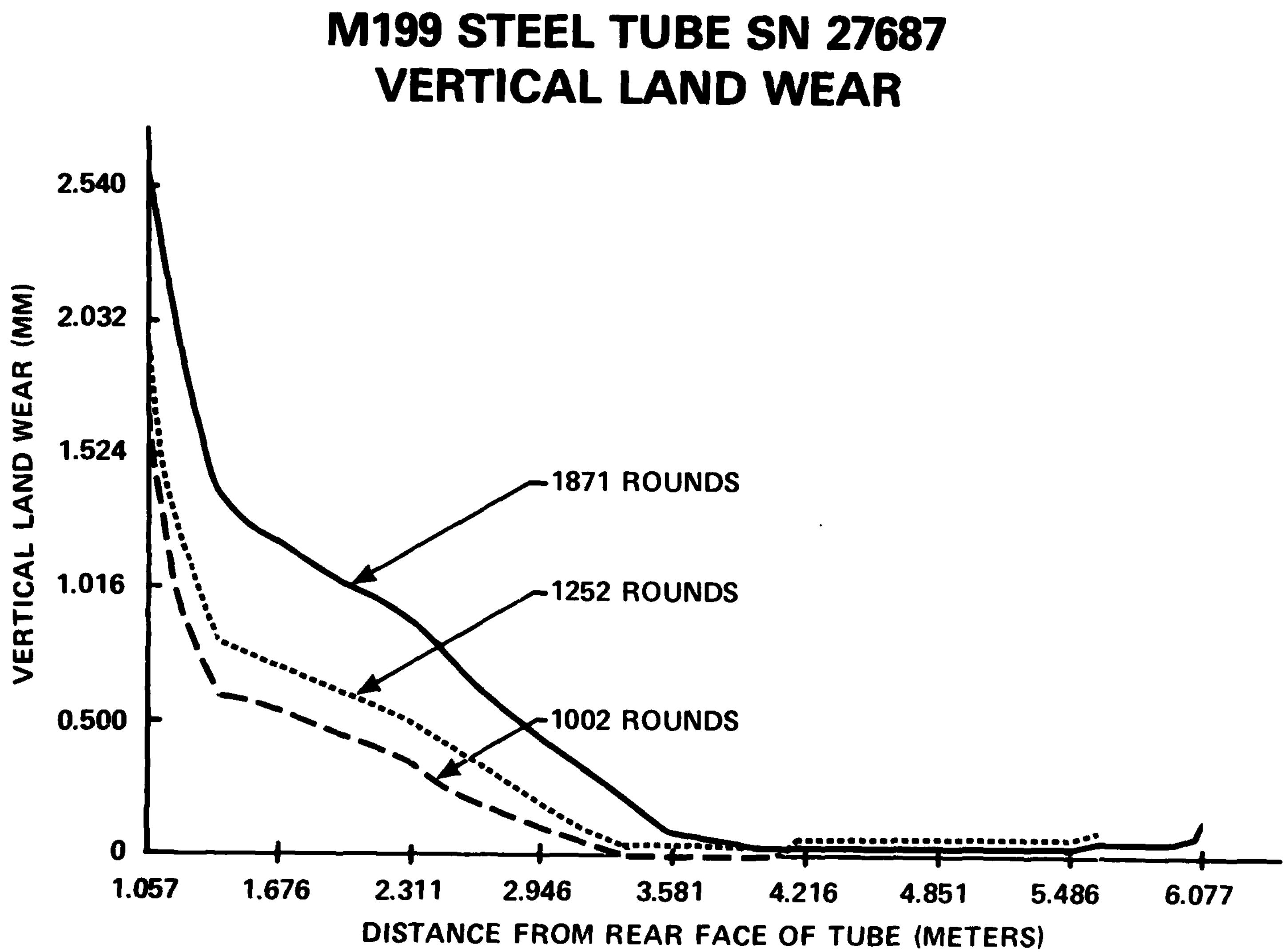

Figure 3. Wear curves for M199 steel tube firing M483A1 projectiles

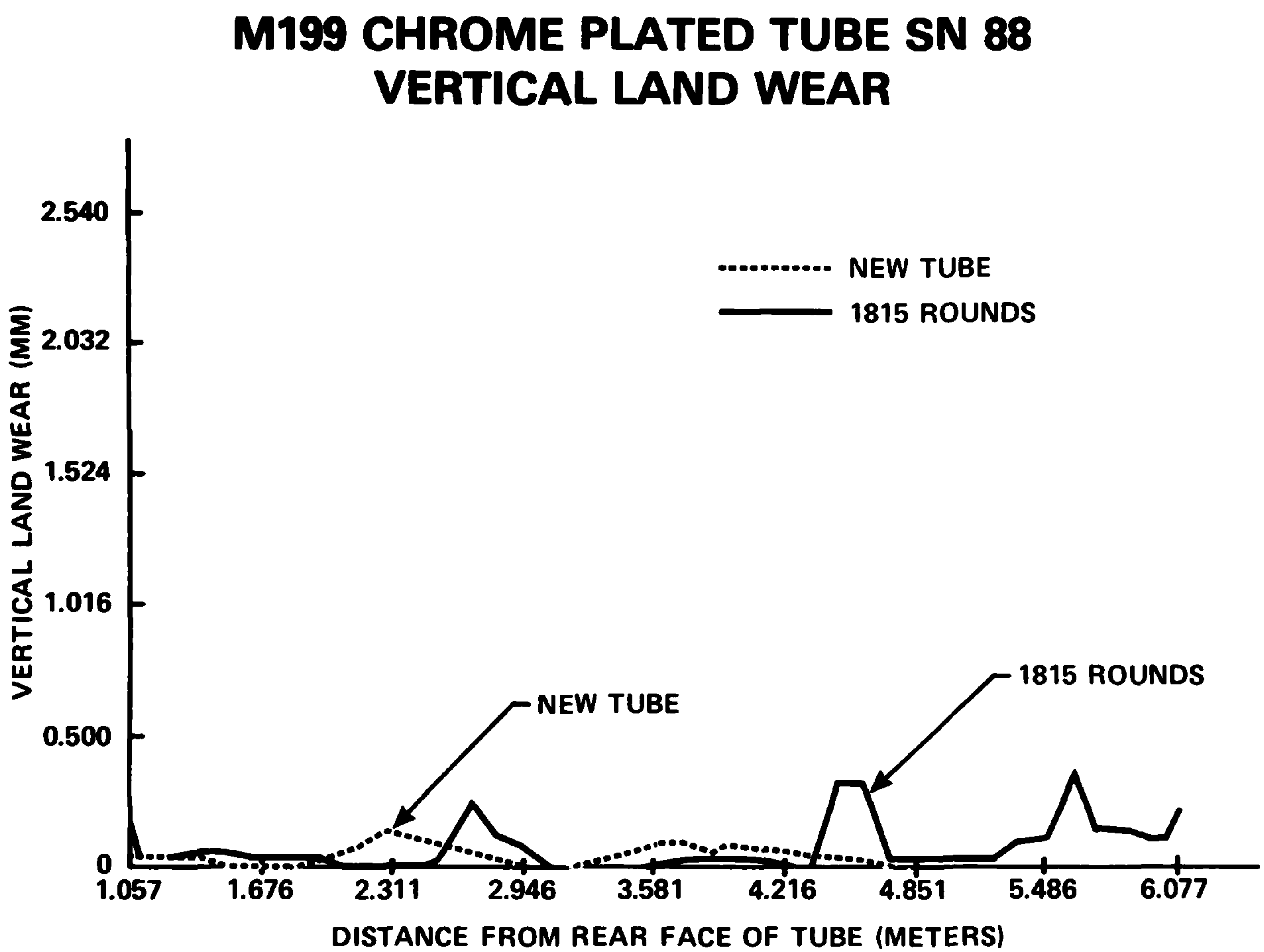

Figure 4. Wear curves for M199 chrome-plated tube firing M483A1 projectiles

Figure 5. Recovered projectiles fired from M199 steel tube SN 27687 after 1500 rounds

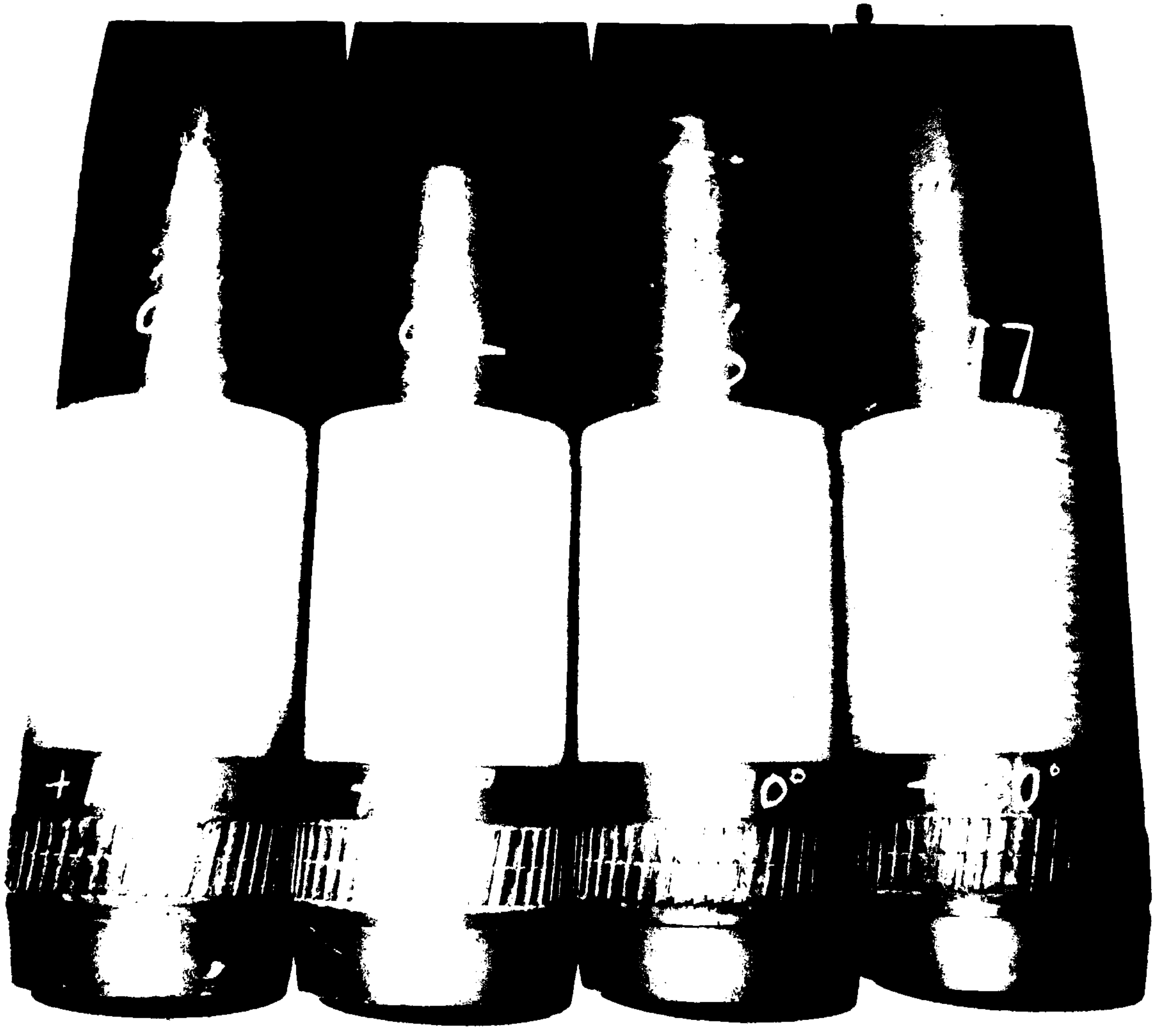

Figure 6. Recovered projectiles fired from M199 chrome-plated tube SN 88 after 1815 rounds

Figure 7. Borescope of origin of rifling region after 1200 rounds fired from a steel tube

Figure 8. Borescope of origin of rifling region after 1800 rounds fired from a steel tube

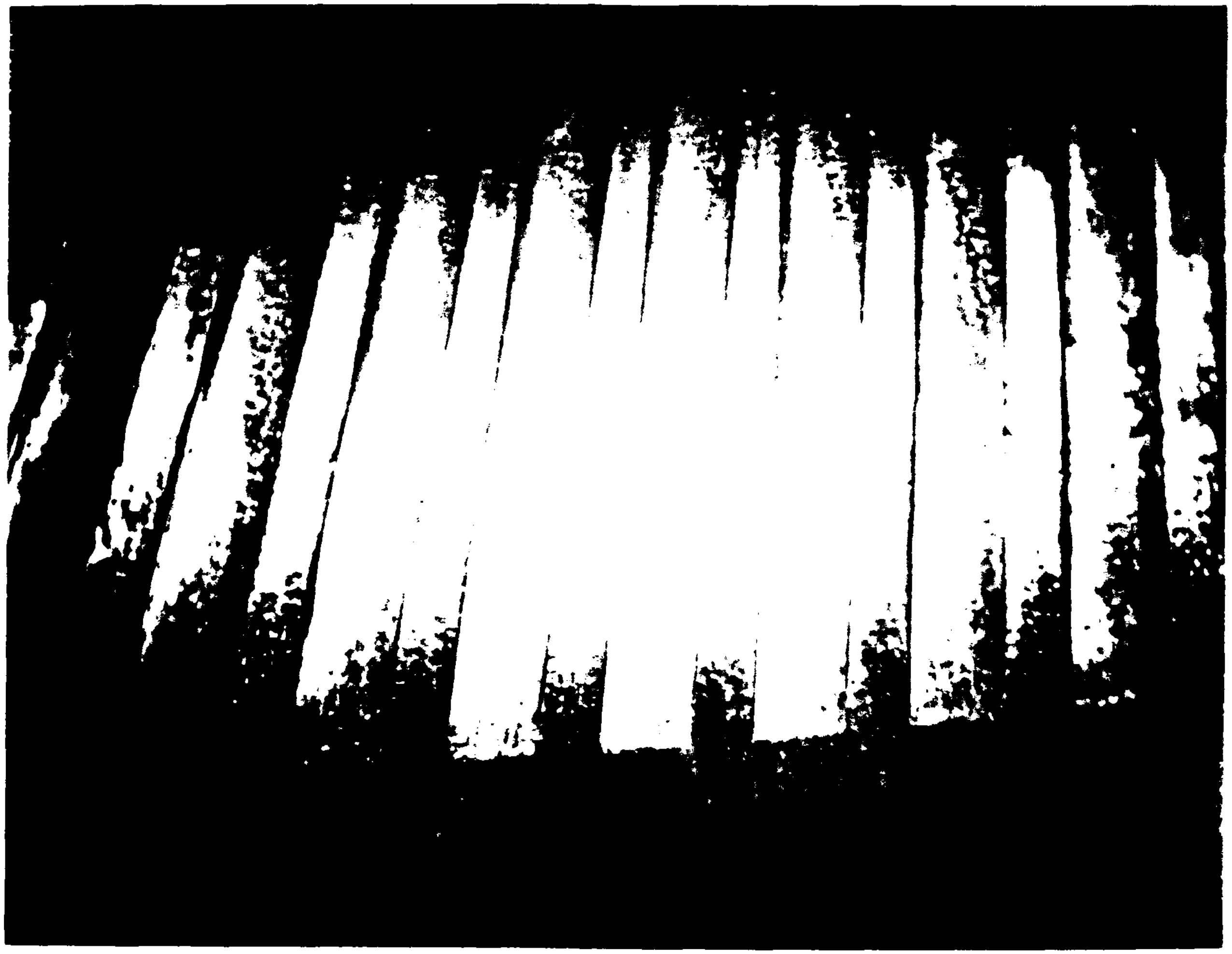

Figure 9. Borescope of origin of rifling region after 250 rounds fired from a chrome-plated tube

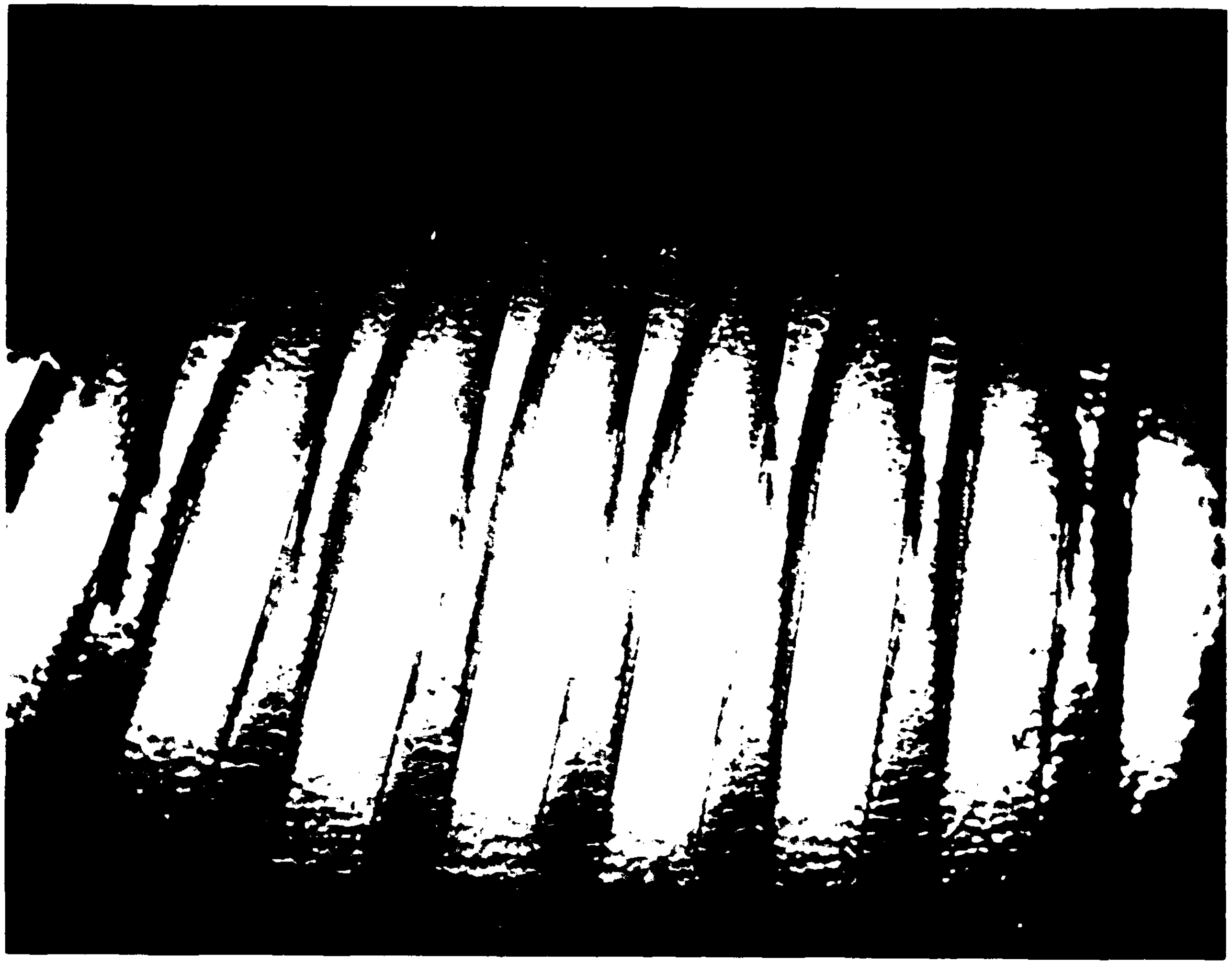

Figure 10. Borescope of origin of rifling region after 1500 rounds fired from a chrome-plated tube

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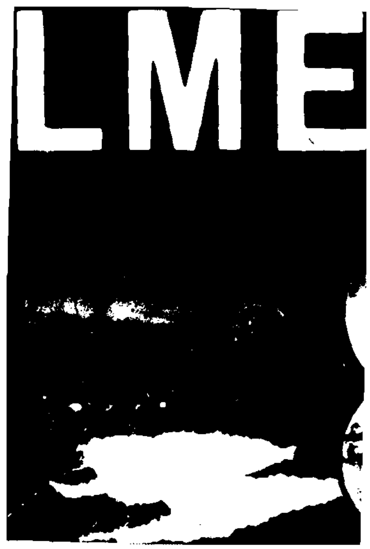
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